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KEYHOLE SQUEEZE-OFF TOOL ENABLES REPAIR OF LARGE (4" & 6") POLYETHYLENE GAS PIPES

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ABSTRACT

Because of the expanding use and progressive aging of natural gas polyethylene (PE) pipelines in the United States, there is a critical need for safe, reliable and cost effective repair. The natural gas industry is moving to "keyhole" access to maintain these pipelines. The critical first step in gas line maintenance and repair is to stop the flow of natural gas using PE pipe squeeze-off tools.

Through research and development with the Department of Energy (DOE) and National Energy Technology Laboratory (NETL), Timberline Tool developed and tested a new squeeze-off tool that provides natural gas utility operators with the means to shut off 4 and 6 inch PE pipe in "keyhole" situations without damaging the pipe**.**

The unique top-down tool design offers the "keyhole" technology needed for safe, reliable and cost effective repair of PE pipe thus ensuring the integrity and reliability of the Nation's gas distribution network.

INTRODUCTION

Natural gas is an increasingly significant energy source for American economic development. It is clean, inexpensive and serves a diversity of important purposes that range from the generation of electricity to the heating of homes.

It has been forecasted that natural gas consumption will grow as much as 50 percent over the next 20 years.[1] By 2020, consumption is projected to run as high as 34.8 tcf (trillion cubic feet). To meet this demand, the number of miles of distribution and transmission PE pipe as well as the size of the piping itself will increase. **Figure 1** illustrates this trend as reported by the U.S. Department of Transportation.

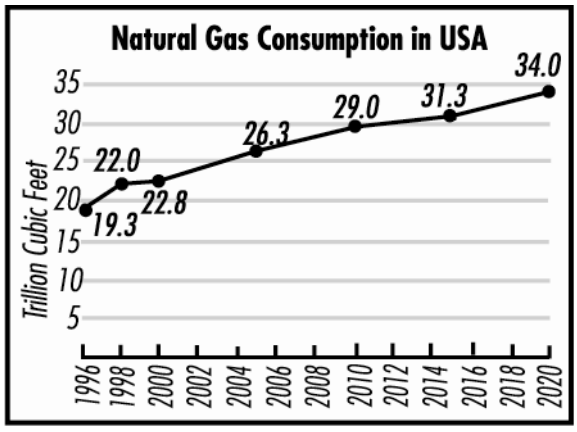

Figure 1

[1] Kyle Simpson, *Proceedings of the Natural Gas Conference: Merging Technologies for the Natural Gas Industry*, DOE's Perspective on Natural Gas, keynote address (Houston, Texas, March 24-27, 1997), p 1.

Maintaining a growing and aging infrastructure

The growth of natural gas consumption has been examined in-depth in a publication entitled *Natural Gas Infrastructure Reliability,* jointly developed by the Department of Energy (DOE) and the National Energy Technology Laboratory (NETL).

The report draws special attention to the need for improved tools for the construction, maintenance and repair of the PE pipe that makes up America's natural gas distribution network. Tools that facilitate repair through "keyhole" excavation situations were preferred by the report.

Keyhole excavation and repair of PE natural gas pipe has significant advantages over traditional, backhoe-style excavations. It allows operators to work on a pipe safely, without climbing down into the ditch, while creating less environmental disturbance. Additional benefits include lower excavation costs and more rapid repair times.

Advances in Geographic Information System mapping, Global Positioning System locating, ground probing radar, electromagnetic detection and acoustic technologies make it possible to accurately locate PE pipes without excavating large holes using a backhoe.[2]

After locating the pipe, new keyhole excavation techniques make use of vacuum equipment to dig a precise hole 8 to 18 inches in diameter. These systems remove a reusable "plug" of pavement, sod or topsoil using a special hole saw and then continue excavating down to the depth of the buried pipe by loosening the soil with an air lance or water jet. The loosened soil is evacuated and held for return after work on the pipe is completed. This type of excavation is found to be less expensive and faster while removing less material from the site. The method results in less disruption to the environment and neighborhood where the work is being performed. Keyhole excavation is becoming more widely used and is encouraged within the industry.[3]

Figure 2

The need for PE pipe squeeze-off tools in keyhole access situations

Once keyhole excavation is completed, a squeeze tool is used to "squeeze-off" the PE pipe and create a complete stop to natural gas flow (**see Figure 2**).[4] Proper squeeze-off of PE gas pipe is the critical first step in the repair process.[5] The squeeze-off capability of PE pipe is recognized as one of the important advantages of the material.

After repair of the pipe, the squeeze-off is released, allowing resumption of natural gas flow. The pipe retains its structural integrity when squeezed correctly with a well-machined tool made to

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[2] Dennis Jarnecke, ed., *Proceedings: GTI Keyhole Workshop* (Tempe, Arizona, April 5-6, 2001).

[3] Dr. Rodney Anderson ed., *Industry Workshop Findings, Pathways for Enhanced Integrity, Reliability and Deliverability, (*National Energy Technology Lab, September, 2000), p 10.

[4] D.R. Stephens, R.N. Leis, R.R. Francini and M.J. Cassady, "Users Guide on Squeeze-Off of Polyethylene Gas Pipes," in *Gas Research Institute*, Vol. 2, (October 1992): p 1.

[5] As cited in natural gas utility company operations manuals (e.g., December 17, 2001 personal communication, Ken Green, Timberline Tool and Anita Romero, Director of Engineering, Southwest Gas, Las Vegas, NV).

specifications determined by the pipe size and wall thickness. As a result, large natural gas grids need not be shut off and service remains intact for all customers but those in the immediate area.

The squeeze-off technique is now routinely used by the natural gas industry for repair of PE pipe and is the first and most important step in any repair situation. Over one half-million PE pipe squeeze-offs are performed annually according to the *User's Guide on Squeeze-Off of Polyethylene Pipe*.[6]

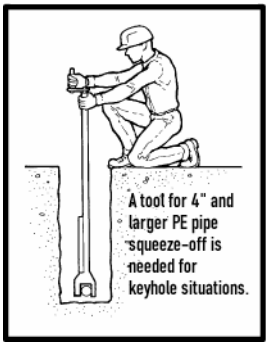

Figure 3

The adoption of keyhole excavation technology brings with it the need for tools that can correctly squeeze-off PE pipe from ground level. A key need for the natural gas industry is a tool that has the capacity to squeeze-off 4 and 6 inch diameter PE transmission and distribution lines in keyhole access situations **(see Figure 3)**. This project successfully demonstrates the feasibility of a new keyhole squeeze-off tool that enables the repair of these large diameter gas pipes.

RESULTS AND DISCUSSION

The overall objective of this project was to demonstrate the feasibility of a squeeze-off tool to rapidly seal off 4 and 6 inch buried natural gas pipelines in "keyhole" access situations while maintaining the integrity of the polyethylene pipe. The specific Technical Objectives are listed below.

1. **Compression Testing and Analysis:** Establish force compression requirements and squeeze-off effectiveness using large diameter squeeze bars on 4 and 6 inch PE pipe.
2. **Initial Tool Conceptual Design:** Establish optimal "squeeze-off" design solutions.
3. **Structural Evaluation:** Establish a preferred design concept which provides for 15% pipe wall compression and uses a 4 inch radius jaw.
4. **Test Tool Construction:** Assemble a test squeeze-off tool for laboratory and field testing
5. **Laboratory Testing:** Establish performance characteristics for the test squeeze-off tool and squeezed pipe
6. **Field Testing:** Establish ease of use and evaluate performance of the test squeeze-off tool in repair and emergency situations, specifically focusing on how the tool design reduces the chances for workers to be injured on the job.
7. **Safety and Integrity Testing:** Establish long-term safety data for squeezed pipe through accelerated squeezed-pipe material aging tests.
8. **Feasibility Assessment:** Detail the technical, market, and economic benefits as a measure of feasibility and as a framework for future R&D requirements.

Summary of Results:

[6] D.R. Stephens, R.N. Leis, R.R. Francini and M.J. Cassady, "Users Guide on Squeeze-Off of Polyethylene Gas Pipes," in *Gas Research Institute*, Vol. 1, (Aug. 1989~Feb. 1992): p 2.

1. Compression Testing and Analysis: The forces required to achieve a range of pipe compressions (0% - 30%) for three different squeeze-off tool jaw radii (3, 4, 5 inch) were determined.

2. Initial Tool Conceptual Design: Four different conceptual designs were investigated for a test tool to meet the project objectives. These concepts were evaluated for desired jaw motion, relative size, and overall performance. The test tool was designed to be lightweight, portable, and operate in keyhole excavations. The selected test tool configuration included jaw displacements that provided 15% PE pipe compression, 4 inch jaw radius and the capability to deliver 14,000 pounds of force at the jaws. The overall length of the test tool is 48" and weighs 60 pounds.

3. Structural Evaluation: Compression tests determined that approximately 14,000 pounds of force is required to compress the walls of the PE pipe 15% with a 4 inch jaw radius. To ensure the reliability and an adequate safety factor in the test tool design, the project team designed the test tool to withstand 40,000 pounds of force**.**

4. Test Tool Construction: In order to verify the viability of the selected design, two test tools were constructed from solid pieces of 6061-T6 aluminum based on design drawings developed for the preferred test tool design **(see Figure 4).** Upon completion of construction, these test tools were subjected to initial functionality tests. They were tested on 4 and 6 inch Medium Density Polyethylene (MDPE) SDR 11.5 PE pipe at 85 psig at room temperature and 0°F to determine effective squeeze-off. Measurements were taken at three points across the yoke of the test squeeze-off tool prior to squeeze-off, during squeeze-off, and after squeeze-off to determine the amount of deflection in the tool. The deflection the tool exhibited was well within the design criteria.

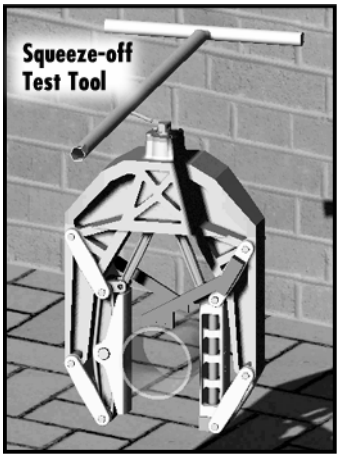

Figure 4

5. Laboratory Testing: ASTM functionality tests were performed on Test Tool #1 in laboratory tests. Additionally, integrity tests were performed on the 4 and 6 inch pipe samples squeezed by Test Tool #1 to determine the effect of squeeze-off on the pipe material. Using 4-inch and 6-inch pipe samples, the test tool was evaluated for operability in general accordance with *ASTM F1563-01, Standard Specification for Tools to Squeeze-off Polyethylene (PE) Gas Pipe or Tubing,* and *ASTM F1734-96 Standard Practice for Qualification of a Combination of Squeeze Tool, Pipe, and Squeeze-off Procedure to Avoid Long-Term Damage in Polyethylene (PE) Gas Pipe* **(see Figure 5)**.

Figure 5

Three (3) specimens of 4 and 6 inch diameter PE pipe were prepared and squeezed. The squeeze was held for 30 minutes. The rate of leakage, if any, was determined using a calibrated rotameter (flowmeter) with 100 psi nitrogen supplied to the specimen while fully squeezed. Various dimensions were obtained during the squeeze procedure.

In addition to inspection procedure within ASTM F1734, the interior and exterior surfaces of the pipe were inspected using scanning electron microscopy (SEM) at the squeeze ear locations (drop-shaped areas of the pipe created as the walls of the pipe are compressed toward each other) **(see Figure 6).**

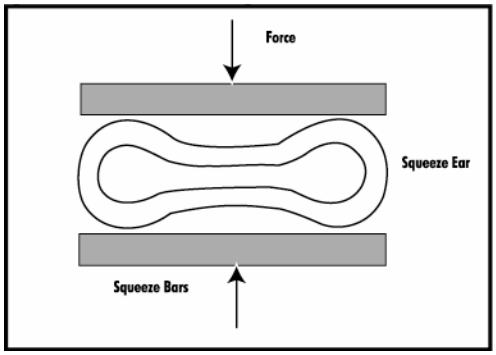

Figure 6

The remaining specimens were non-destructively inspected on the exterior only. The two (2) remaining 6-inch specimens and one (1) of the remaining 4-inch specimens were then pressure tested. The results of these tests confirmed the effectiveness of Test Tool #1 to squeeze-off the 4 and 6 inch PE pipe without damaging the pipe.

The squeeze-off test tool was evaluated for release protection, release rate, flow control, grounding, squeeze-bar configuration, over-squeeze protection, and squeeze bar spacing. Evaluations revealed that the force could only be released by unscrewing the tool. The operator controls the rate of release manually. The actual squeeze percentages (wall compression) were significantly less than specifications. Thirty percent compression is the maximum allowable under ASTM Designation F 1041. The lengths of the squeeze bars were sufficiently long enough to squeeze-off 4 and 6 inch pipe.

6. Field Testing: The test tool validation tests were conducted in accordance with *ASTM F1563-01, Standard Specification for Tools to Squeeze-off Polyethylene (PE) Gas Pipe or Tubing.* Specifically, Sections 5.3 Release Protection, 5.4 Release Rate, 5.5. Flow Control, 5.6 Grounding. In all instances, the test squeeze-off tool met or exceeded the ASTM and company specifications.

Field tests with natural gas utility partners demonstrated the capability of the squeeze-off tool to stop the flow of gas with 15% pipe compression, the tool design point. Incipient squeeze-off occurred at about 5% compression in the tests, demonstrating adequate safety margin in the tool design to insure squeeze-off at all conditions **(see Figure 7)**. Response from the natural gas operators was extremely positive concerning the ease of use and efficiency of the new squeeze-off tool in keyhole access situations.

Figure 7

7. Safety and Integrity Testing: Accelerated age testing on squeezed PE pipe samples was performed to assess long-term safety and structural integrity of the squeezed PE pipe samples. These results revealed that the integrity of the pipe was maintained. Accelerated preliminary testing on squeezed pipe samples was performed to assess the long-term safety and structural integrity of the pipe. The safety and integrity sustained pressure testing was conducted in accordance with *ASTM D2513, Standard Specification for Thermal Gas Pressure Pipe, Tubing, and Fittings.*

8. Feasibility Assessment: The technical feasibility of the proposed squeeze-off test tool was demonstrated conclusively. The successful demonstrations of the keyhole squeeze-off tool at natural gas utility test sites, the enthusiastic response of utility representatives, and the supporting laboratory tests and analyses provided convincing evidence for technical feasibility.

Numerous natural gas utility companies have expressed need and support for the development of this squeeze-off tool for large diameter (4 and 6 inch) PE pipe. The information obtained through collaboration with key industry personnel shows strong evidence for the commercial market for this new keyhole squeeze-off tool.

CONCLUSION

The squeeze-off tools currently available for large diameter (4 and 6 inch) PE pipe cannot be used for performing repairs in keyhole and confined space situations. They require operators to work in the trench; they require extensive excavations at the repair site; they are cumbersome and heavy to use; and they require insertion under the pipe.

The new squeeze-off tool was designed specifically for keyhole applications and will enhance the safety of workers and neighborhoods in the following specific ways:

- Remote top-down operation keeps the worker out of the trench and away from blowing gas.
- Keyhole application does not require large excavations and creates a safer environment for workers and surrounding neighborhoods.
- Operators are able to perform the repair work more quickly and in smaller areas decreasing the chance of danger to themselves and to others in the area.
- Built from high strength aluminum alloy, this new squeeze-off tool protects the operator in situations where blowing gas could spark an explosion.

The new squeeze-off tool demonstrated reliable squeeze-off when field tested on 4 and 6 inch PE pipe. Utility operators were consistently able to squeeze-off the pipe without inducing damage. The reliability benefits of the keyhole squeeze-off tool are:

- Limited pipe compression is built into the tool so it cannot over squeeze the pipe.
- Operators can control the squeeze-off and release rate preventing pipe damage.
- The squeeze tool geometry (i.e. 4-inch squeeze bar radius) enables reliable squeeze-off with less pipe compression.
- The tool is designed to center the pipe in the jaws, eliminating visual guidance or other means to insure proper positioning for a safe squeeze-off.

• The screw actuating mechanism in the tool prevents uncontrolled quick release that could damage the PE pipe.

Current procedures for repairing buried natural gas pipe requires excavations upstream and downstream from the rupture so that the leak can be isolated by "squeezing off" the flow of gas on either side of the damage. The damaged section of pipe is then removed and a new section inserted. These repair procedures are time consuming and expensive. Keyhole access to squeeze-off and repair natural gas pipelines will enable major cost savings for utilities. The proposed squeeze-off tool will operate through keyhole access and provide major cost savings by:

- Reducing squeeze-off time.
- Reducing the size of the excavation required for squeeze-off.
- Reducing the pavement restoration effort.
- Increasing productivity – a single operator can perform the repair.
- Increasing the efficiency of the overall squeeze-off and repair process, which will result in less labor hours and unaccountable gas loss.

Further development of the new keyhole squeeze-off tool will result in a device that will operate in a much smaller surface excavation and thereby substantially lower the time and cost of repairing 4 and 6 inch diameter gas distribution piping.

An engineered prototype of the new squeeze-off tool is being developed during Phase 2 of this DOE/SBIR project in preparation for commercialization. This new tool will provide natural gas utility operators with the means to shut off 4 and 6 inch PE pipe in "keyhole" situations without damaging the pipe.

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